

Appendix 3-1

PV System Design Report



INTERNATIONAL

Timahoe North Solar Farm - PV System Design Report

ESB Wind Development Ltd and Bord na Móna
Powergen Ltd

Document No.: QS-000218-01-R600-001

Date: June 2018

ESB International, One Dublin Airport Central, Dublin Airport, Cloghran, Co. Dublin, Ireland.

Phone +353 (0)1 703 8000

www.esbinternational.ie

File Reference:	QS-000218-01	
Client Recipient:	/ ESB Wind Development Ltd and Bord na Móna Powergen Ltd	
Project Title:	Timahoe North Solar Farm	
Report Title:	Timahoe North Solar Farm PV System Design Report	
Report No.:	QS-000218-01-R600-001	
Volume:	1 of 1	
Prepared by:	Nikolas Konstantopoulos	Date: 16/05/2018
Title:	Solar Engineer	
Verified by:	Annmarie Downey	Date: 07/06/2018
Title:	Project Manager	
Approved by:	Mark Fielding	Date: 13/06/2018
Title:	Manager, Pre Development Group Civil & Environmental Engineering	

Copyright © ESB International Limited

All rights reserved. No part of this work may be modified, reproduced or copied in any form or by any means - graphic, electronic or mechanical, including photocopying, recording, taping or used for any purpose other than its designated purpose, without the written permission of ESBI Engineering & Facility Management Ltd., trading as ESB International.

Template Used: T-020-007-ESBI Report Template

Change History of Report

Date	New Revision	Author	Summary of Change
February 2018	0	NK	Draft report issued for comment.
May 2018	1	NK	Final Report. Revision to MEC. Sections 6 and 7 amended. Appendix 1 added.
October 2018	2	NK	Client name changed. Revision to sections 2,7, 12 and Appendix 1.

Contents

1	Introduction	4
2	Grid Capacity	5
3	PV module	6
3.1	Module technology	6
3.2	PV Module Specification	7
3.3	System voltage of PV module	8
3.4	PV module case	8
4	PV strings	9
5	PV tables	9
5.1	PV tables orientation	9
5.2	Module arrangement	10
5.3	PV row spacing	10
5.4	PV table tilt angle	11
5.5	PV table system and piling	11
5.6	PV table length	12
6	Inverters	12
6.1	Inverter type	12
6.2	Inverter locations in the layout	15
6.3	Inverters pads	15
7	Total DC capacity and DC/AC ratio	16
8	Cabling	17
8.1	String DC cable	17
8.2	Main DC cable	17
9	Combiner boxes	18
10	Medium voltage cables and Switchboard	18
11	Substation	18
12	Storage systems	18
13	Earthing	19
14	Access roads	19
15	Construction compound	19
16	Peat storage areas	19

Timahoe North Solar Farm – PV System Design Report

17	Shadowing	19
18	Drainage	20
19	Fence and CCTV	20
	Appendix 1 – PVSyst Report	21

1 Introduction

This report has been prepared by ESB International to describe the PV System design for Timahoe North Solar Farm.

One of the primary design challenges for the design of this project is the unusual ground conditions (wetland consisting of peat) which leads to two main technical issues:

- The usual methodology for mounting the PV tables and the rest of the equipment (inverters, roads etc) on the ground is not suitable for the peat soil and a custom made solution needs to be identified in order to have a secure and relatively cost effective method.
- The access to the site will be challenging and special civil engineering methodologies will be required during the construction.

This report focuses on the design decisions for the solar PV system and mainly on the DC side of the system, including the inverters. Other reports to support the planning application are prepared under separate cover including;

- Report on the construction methodology
- Report on the foundation construction methodology
- Drainage Design Report and drawings
- Peat Stability Risk Assessment

A number of drawings related to this design were prepared for Timahoe North Solar Farm to be submitted as part of the planning application. The drawings are listed in Table 1-1

Drawing title
Module layout
Elevation-Inverter (40 ft container)
Section & Elevation-PV Table
Elevation-CCTV
Elevation-Welfare 40 ft Container
AC(MV) cables layout
Sheep fence
Elevation-Deer fence & Gate
Elevation-Storage 20t Container
Trenches sections-1
Trenches sections-2

Elevation-Switchboard in North site (40 ft container)
Elevation-Antennas & weather station

Table 1-1: List of drawings

2 Grid Capacity

The export capacity for the solar farm is designed for 70 MW with a power factor (PF) equal to 0.95 (leading and lagging). The battery storage is currently designed for 20 MW with the resulting total export capacity for the combined system to be 90 MW. This is based on current battery technology and may change subject to agreement with the grid operator.

3 PV module

The PV module considered for Timahoe North is a typical 60cell polycrystalline PV module:

Company:	Qcells
Model:	Q.PLUS-G4.2 270-280
Technology:	polycrystalline silicon (poly-Si)
Power:	270 Wp
Size:	1.67 m x 1 m x 0.032 m
Number of cells:	60
Maximum system voltage:	1500 V
Case:	Anodized aluminum frame, glass in front, composite film on the back

Table 3-2: PV Module

Most of the design decisions have been based on the above PV module specifications. However there is flexibility to use other modules. The final module selection will be based on a number of factors.

Below is a description of some of the alternative options considered for Timahoe North and their advantages.

3.1 Module technology

The most common PV module technology used worldwide is the crystalline silicon (c-Si) and most specifically the polycrystalline poly-Si technology. For Timahoe North the poly-Si is proposed as it has a lower cost than monocrystalline and it is more commonly used in large scale projects where the availability of land is not very limited. The reason for this is that in previous years the additional efficiency (and thus power capacity per m²) of monocrystalline modules did not justify the increased price apart from when the available space was too limited to reach the desired power capacity e.g. in roof applications. However monocrystalline modules are becoming cheaper and even more efficient and they might become more popular in large scale applications in the future. For planning purposes, the poly-Si technology has been considered. However, there is flexibility to switch to other technologies if required including monocrystalline, PERC, half-cell, thin film or other.

The design report will be oriented around c-Si modules only and mainly polycrystalline.

3.2 PV Module Specification

The size of a PV module determines the capacity. The most common sizes for poly-Si modules are the 60 cells and the 72 cells modules. Other sizes (e.g. 36 cell) are not common in utility scale applications.

72 cells PV module:

The 72 cells module is a large PV module of approximately 2 m x 1 m size. These modules are designed for utility scale projects like Timahoe North. They have more capacity than a 60 cells module e.g. Capacity can be 350 Wp or more.

Advantages of a 72 cell PV module:

- It requires less clamps for mounting on the PV table, and for the same DC capacity less modules are needed.
- It requires less time to be installed and less movements across the site.

60 cells PV modules:

The most common PV module size in many markets the last few years was the 60 cells polycrystalline module. This is typically circa 1.67 m x 1 m and the capacity is between 250 Wp -280 Wp or greater (lately some 60 cells models have been released that reach 310 Wp).

Advantages of a 60 cells module:

- The 60 cells module to date have been the standard size for many markets, as for example the UK market, even for utility scale projects. For this reason they are more easily available (e.g. if replacement modules are needed).
- Some module manufacturers claim that the 60 cells series are more readily available than the 72 cells as the latter require a special order in order to be produced. Also if an order is required, then this usual order would be subject to a minimum quantity of modules and this makes the process more difficult from the O&M perspective.
- A 60 cells module is more versatile during construction as it is lighter and smaller than a 72 cells module. For this reason they can be installed easier (in some cases, by one person). This is an even more important consideration for the Timahoe North project because of the difficult ground conditions at the site.
- The 60 cells module can be used with the slide-in PV table type (this slide in system is described in more detail in section 5.5 below).

Selected PV module size for planning:

For Timahoe North design for planning, a 60 cells module, with 270 Wp capacity and 1.67 m x 1 m physical size has been considered:

- The smaller 60 cells module is considered more versatile for Timahoe North where the ground conditions are difficult and there is a need to eliminate the use of any additional or bespoke equipment on site.

- The 270 Wp module capacity allows more flexibility for the final module layout design. For example, during the final design, some areas might be excluded from construction and so some PV tables maybe removed. In this case the target DC capacity could be achieved by using modules with higher capacity e.g. 280 Wp.

The planning should not pose any restriction in the use of a different module size for the final design.

The selection of the module size will be dependent on the potential EPC company that is procured to install the solar farm. Some EPCs prefer to use one specific module type because they have incorporated the use of this type of module in their construction methodology.

3.3 System voltage of PV module

The system voltage of the PV module considered for Timahoe North is 1500 V. Recently this is becoming the standard voltage and it allows a lower Balance of System (BOS) cost (previously, the standard voltage for utility scale projects was 1000 V). The module system voltage should match that of the inverter maximum input voltage and generally all the DC side of the PV system should be designed in accordance with this voltage.

3.4 PV module case

The most common PV module casing consists of an aluminium frame, glass in front and a synthetic material on the back. This is the type of casing that has been considered for Timahoe North solar farm. However other types can be used for the actual construction as for example, glass-to-glass.

Glass to glass case:

The glass to glass case consist of glass on the front and back side and it does not have a frame. The advantages of glass-to-glass are the following:

- It has better PID resistivity. PID stands for Potential Induced Degradation which is a phenomenon where there is exchange of ions between the semiconductor material and other elements of the module e.g. the glass, the aluminium frame etc. The factors that contribute to this phenomenon are high ambient temperature, high humidity and the high voltage potential as well as the low manufacturing quality of the module. PID can cause a considerable loss in module capacity. The absence of an aluminium frame in glass to glass modules can contribute to mitigating this as a big part of the PID phenomenon takes place between the PV cells and the aluminium frame that most modules have.
- Some glass-to-glass manufacturers provide 30 years warranty against PID issues (it should be mentioned however that the newer aluminium frame models from reputable companies are claiming excellent PID resistance).
- They have better self-cleaning capabilities because of the lack of the frame as there is no soil accumulation at the edge of the panel.

- The lack of aluminium frame is advantageous in environments where there is a higher probability for the aluminium case being corroded. In Timahoe North, the peat soil is considered to be acidic so this might be a reason for considering glass to glass casing during the final design.

The selection of the PV module case depends on the PV table selection as well. For example, some PV mounting systems (slide-in systems) require an aluminium frame only – a glass to glass module would be too thin for the guides of this system and too vulnerable. With this system there are up to 6 modules in landscape placed in a way that they are supported by the weight of the module above.

4 PV strings

The string size (number of modules per string) will be defined after the selection of the PV module model that will be used in construction. The reason for this is because certain specifications are needed from the module datasheet in order to calculate the maximum possible number of modules in the string. Generally the goal is to have the maximum number of modules possible as the higher the total voltage of the string the lower the resistive losses.

The string maximum voltage is dictated by the maximum input voltage of the inverter. This is 1500 V for the inverter considered for Timahoe North. The total DC voltage of the string should never exceed this.

The calculation of the total DC voltage of the string is not straightforward as the PV module has a different voltage under different environmental conditions. The process to calculate the maximum number of modules per string involves the calculation of the maximum possible voltage of the module for the environmental conditions of the area that it will be installed.

For planning purposes the string length was calculated at 34 modules per string but this may vary in the final design.

5 PV tables

5.1 PV tables orientation

The orientation of the PV tables at Timahoe North is Southerly. This is the optimal orientation regarding the energy production per installed capacity. West – East was considered for the site but found to be unsuitable because this arrangement is not optimal energy production per installed capacity. More specifically the annual energy per installed capacity for West-East is approximately 10-15% lower than the southerly arrangement. This is a strong indicator that the West - East arrangement is not a good option for Timahoe North. Also there is availability of land in Timahoe and this makes the West - East arrangement less appealing (the West - East arrangement is particularly popular in areas where there is a shortage of land or the cost of land is high).

However once there is greater visibility on the economics of the project, a better evaluation will be possible. For example, the price of the solar PV systems is

expected to fall further in the near future and this could make the West - East arrangement more reasonable.

5.2 Module arrangement

As shown in the “Section & Elevation-PV Table” drawing, the module arrangement on the PV tables can be:

- Portrait up to 4 modules in width (4 in portrait or 4P)
- Landscape up to 6 modules in width (6 in landscape or 6L)

Generally, from an energy production perspective, it is preferred to have a landscape arrangement as the inter-row shading has less effect on the module production compared with the portrait arrangement. It is also generally preferable to have more PV modules on each table in order to minimize the number of tables required.

The gaps between the panels on the table are usually between 2-5 cm. These gaps are required to

- a) Facilitate the construction process (as there is available space between the modules for the workers fingers),
- b) Provide a buffer in case of thermal expansion of the structure and
- c) Allow the rain water to drain between the modules instead of accumulating in the front of the table.

For the module layout design for planning, a 4L table was selected with 2 cm gaps between the PV modules.

5.3 PV row spacing

The PV row spacing refers to one of the following:

- Front to front distance (sometimes referred as pitch): This is the distance between the front side of the tables of one row and the front side of the tables of the next row.
- Back to front distance: This is the available space between the PV rows and refers to the space between the back side of the tables of one row and to the front side of the tables of the next row.

The PV row spacing should be selected in order to facilitate the following:

- It should be wide enough to avoid the inter-row shading as much as possible. However some inter-row shading is unavoidable - for example during the early hours of the day. This depends also on the selected tilt angle of the table.
- The front-to-back distance should be wide enough in order to allow O&M activities. For Timahoe North, the front to back distance should not be less than 5 m. For example, it should be possible for a machine for vegetation cutting to drive between the tables.

For the module layout design for planning, the following was selected:

- Front to front distance: 9 m. This is a common distance for solar PV in similar geographical areas.
- Front to back distance: 5.1 m

It should be noted that for planning purposes, worst case for the row spacing is considered the more dense arrangement (tables close together). The ranges shown in the planning drawing “Section & Elevation-PV Table” cover many options including a dense table arrangement.

5.4 PV table tilt angle

The ideal fixed tilt for a PV module in Timahoe North area, in order to generate the maximum power per year (assuming there is no shading as for example inter-row shading) is approximately 38 degrees. However inter-row shading cannot be avoided completely so the tilt angle should be reduced. Another reason for reducing the tilt angle is due to the high wind loads in Ireland.

Front-to-front distance of the tables for planning purposes has been defined as 9m. For this distance, the optimal tilt for energy production was calculated approximately around 25 degrees using PVsyst simulations. The most common tilt that has been used by many EPCs in similar geographical areas in Europe is 20 degrees. This angle was selected for the planning design as the difference in energy production is not significant compared with the 25 degrees.

In the drawing “Section & Elevation-PV Table” various ranges have been shown for the tilt angle and the front-to-front distance. The final tilt definition of the tables depend on a number of variables:

- The number of module in width (e.g. 4L or 6L): The higher the back of the table, the lower the tilt angle should be kept.
- The table system that will be used. Some systems require a certain module arrangement and tilt angle, for example a slide-in 6L table from a well-known company has a fixed tilt of 12 degrees.

5.5 PV table system and piling

Typical PV table systems available in the market are aluminium or steel (or combination of both) structures with an above ground frame for the PV modules and an underground piling system. The modules are mounted on the frame by using clamps or they are mounted directly on the frame using screws. There are also some variations as for example a table with a frame that allows modules to slide in without having to use clamps / screws for each one. This system allows a much quicker mounting of the modules and it should be considered.

The piling system of the table will need to consider the peat depth of each area of the site. It is expected that long piles will be used at Timahoe North and the underground length will vary between 2 – 5 m.

Sun tracking systems were not considered since the amount of direct sun irradiation is relatively small for Ireland and the cost of this system does not justify the use of them.

5.6 PV table length

Ideally the length of the table should be equal to the length of the PV string. For example for a 4L table with 34 modules-string, the length of the table should be equal to the length of each module multiplied by 34 plus the gaps between the modules.

- Module length: 1.67 m
- Gaps between modules: 0.02 m
- Total table length $(1.67 \times 34) + (33 \times 0.02) = 57.44$ m

Some EPCs suggest dividing PV tables into two smaller tables. The reason for this is that a very long table might have stability issues for example thermal expansion issues. Other EPCs mitigates this issue by applying flexible connectors along various segments of the table. Usually it is more economical to have one long table instead of two smaller tables. The final decision will be based on the potential EPC and the PV table system.

In the event that the table has to be divided into two smaller tables, each string cable will run in two tables and a flexible duct will be required for protection of the part that is suspended between the two tables.

6 Inverters

6.1 Inverter type

The main inverter types that are used in large scale projects (e.g. >2 MWp) are central and decentralised inverters. The central inverters come in containerised (indoor) and outdoor versions. Below is a summary of the advantages of each option and the type that was selected for Timahoe North.

Containerised central inverter:

These inverters come encased in a standard 20 ft or 40 ft (or other size) container . The inverter, the transformer and HV switchgear are included in the container.

The main advantage of the containerised inverters is that the main components (inverter, transformer, HV switchgear) are preassembled in the factory and this limits the amount of work needed on site and other logistics, which is very important considering the difficult terrain of Timahoe North and the possible unfavourable weather conditions during construction.

The 20 ft containerised inverters currently reach a capacity of approximately 2.5 MVA. The 40 ft inverters can reach a capacity of approximately 5 MVA and they usually contain two inverter units, one or two transformers and one switchgear.

A disadvantage of this containerised system for Timahoe North is the weight of this - for example a 20 ft inverter might weigh 16 tn and the access to the Timahoe North site may pose difficulties considering the crane required to unload and position these inverters.

Outdoor central inverters:

These central inverters share similar technology to the containerised inverters but they usually come in three separate main pieces and are assembled on site: The inverter (sometimes two inverter modules), the transformer and the switchgear. These three systems should be installed on a concrete pad.

An advantage of this system is that each of the three units comes separately and they are smaller and lighter to be transferred on site and this is very important for Timahoe North considering the site ground conditions.

Decentralised inverters:

In the past, for large scale solar PV projects over a certain size e.g. 2 MWp, the standard option for inverters was the central inverters. In the last few years, some large scale projects have been built with decentralised inverters (also known as “string inverters”) as these are becoming more popular for large scale applications.

The decentralized inverters have some advantages such as:

- All the strings are monitored separately. This is an important advantage and it reduces the O&M cost as it saves time in identifying the problematic string. This is important for health and safety during maintenance as it is immediately known which string is problematic and potentially short circuited (string monitoring can be used with central inverters in combiner box level but this is more expensive).
- Many MPPT inputs. It is possible to group the lowest string in each table to the same MPPT and have slightly better yields. The way this works is that each MPPT works as an independent input of the inverter and it is preferable to have strings of similar power (e.g. similar shadowing, same orientation etc.) grouped together in the same MPPT as this gives maximum energy. This is important for projects with a lot of shadowing, many orientations etc. This does not apply at Timahoe North but it will still give slightly higher yields. In practice though, it might be very difficult to group the lower level strings in the same MPPT because of the amount of additional work needed for a project of this size.
- No need for extra telecom cables because the monitoring signal travels through the power cables (PLC technology). So there is saving in cables, trenches, ducts, working hours and maintenance costs.
- Decentralised inverters are low weight compared to the central inverters and this is advantageous in peat bog sites like Timahoe North.
- With decentralised inverters it is possible to avoid underground DC cables (string DC or main DC) completely by using over ground cable ladders. This can decrease the cost significantly as underground cabling installations are usually more expensive than over ground.

For Timahoe North the use of decentralised inverters have some benefits as described above. However the use of central inverters for large projects of the size of Timahoe North is still recommended by most EPCs and manufacturers as it simplifies the construction. It also helps the O&M process as with fewer and more robust inverters, issues relating to the inverters are not very frequent (with small decentralised inverters in larger numbers, it is far more common to have inverter faults and O&M personnel need to be on site servicing more often). The inverter type will be selected during the final design. For planning purposes, a 40 ft containerized type inverter model is shown in the drawings because this has the greatest visual impact from a planning perspective and it is possible to be replaced with other smaller size inverters. The grid requirement at the point of connection is 70 MW with PF = 0.95 (leading or lagging). However a need for lower power factors might occur which can cause the curtailment of part of the active power injection and thus loss of profit. For this reason, before finalizing the inverter sizing, special studies such as power flow analysis and inverter analysis (e.g. P/Q diagrams) should be carried out. From these studies, a more accurate sizing of the inverters will be possible so the PV system will be able to inject 100% of its active power to the grid and concurrently provide the required reactive power. At this stage these studies are not available and for the purposes of this report the number and capacity of the inverters were calculated using simplified calculations. Assuming that the average PF can be between 0.8 and 1 we have:

For PF=1 and assuming inverters with capacity of 2.5 MVA 28 inverters are required as $28 \times 2.5 \text{ MVA} = 70 \text{ MVA} = 70 \text{ MW}$.

For PF=0.8 (this PF is quite conservative) approximately 88 MVA of total apparent power from the inverters is required. Assuming that inverters with 2.75 MVA capacity will be used then the required number of inverters is $88 \text{ MVA} / 2.75 \text{ MVA} = 32$. However each inverter should limit its active output in order that the total sum never exceeds 70 MW. So for the 32 inverter example, each one should limit the active power export to approximately 2.18 MW.

As described above for PF = 0.8 or 1, the number of central inverters can be between 28 and 32 and the capacity of each can be between 2.5 MVA and 2.75 MVA. Other combinations with central inverters are also possible (or even decentralised inverters can be used) and this will be defined during the final design. For planning purposes, 29 inverter locations with 2 x 40 ft containerised inverters at each location are shown in the "Module layout" drawing. This allows for sufficient planning flexibility.

Regarding the energy estimation with PVsyst, it was assumed that PF=1 and 28 x 2.5 MVA inverters were used (Appendix 1). This gives $70 \text{ MVA} = 70 \text{ MW}$ (PF=1). This gives a good estimation of the active energy yield that can be achieved from the system. In reality, in order to achieve this yield the inverters should probably be oversized (e.g. 32 x 2.75 MVA) because they should be able to provide reactive power as well, as mentioned above, however the active energy estimation will be very similar. When the final design arrangements of the system (inverter and PV modules for example) will be known then a more accurate PVsyst report will be prepared.

The number, type and size of the inverters at each location can be different once planning is granted and it will be possible:

- To replace one or both of the 40 ft inverters with 20 ft inverter containers or outdoors inverters.
- To remove one or both of the 40 ft inverters.
- It will be possible to switch to decentralised inverters for the actual construction application. These have smaller foot print and they are usually installed under the PV tables so their visual impact is less than central inverters. In this case, the central inverters will not be installed and there is no need to install any type of mock-up container. However the transformers and the HV switchboard will still be required and they can be installed in the inverter locations as shown in the planning drawings.

The size of the inverter system arrangement in the drawings (both in the “Module layout” and the “Elevation-Inverter (40 ft container)” drawing) is large enough to represent many central inverter systems available on the market as for example the following models:

- Schneider Electric - Conext SmartGen Power System 2 x 2000 kVA (1500 V)
- ABB outdoor system with 2 x PVS980, transformer and switchboard
- ABB skid (indoor-containerised) system 2 x PVS980, transformer and switchboard
- SMA MVPS 5500SC-EV (40 ft container)
- SMA SUNNY CENTRAL 2750-EV

Regarding the DC input voltage of the inverters, 1500 V has become the standard. This is recommended as it allows the cost of the BOS to be reduced.

6.2 Inverter locations in the layout

The inverter locations were selected based on the PV tables arrangement following the concept described below :

It is preferable to have the minimum possible length for main DC cables so the voltage drop can be avoided as much as possible. It is not possible though to have all the PV tables at the same distance from each inverter so unavoidably there is different voltage drop for every main DC cable. The best way to mitigate the voltage drop issue is to avoid having excessive lengths of main DC cables by installing the inverter approximately in the middle of the PV tables that they will be connected to. This concept was applied to the module layout.

6.3 Inverters pads

The inverter pad is the area in front of the inverter that is reinforced with similar material to the access roads. The purpose of this is to facilitate the truck and crane movements during the delivery of the inverter or during a replacement of the inverter in the future.

The pad should be large enough to allow the crane to make a U-turn. The size that was selected for planning is 25 m x 25 m.

7 Total DC capacity and DC/AC ratio

While the solar farm export capacity to the grid is designed for 70 MW and the inverters have been selected in accordance to this limitation, the high availability of land allows a higher DC capacity installation which will result in a higher DC/AC ratio. The DC/AC ratio is the ratio between the installed DC capacity and the total AC export to the grid from the inverters. The installed DC capacity is the total installed capacity of the PV modules and defined as Wp which means Watts-at-the-peak-point indicating the peak energy production of the modules (The peak energy production of the modules is the nominal energy produced under Standard Test Conditions (STC) as defined by the datasheet. In environmental conditions other than the STC, the module will have a different capacity so by convention, the peak point capacity is considered as the nominal. The environmental conditions that have the biggest impact in the actual power export of a PV module is the irradiance and the cell temperature – the latter is affected by the ambient temperature, the wind speed, the solar irradiance etc).

The concept of a high DC/AC ratio is common in countries with long periods of relatively low sun irradiation and it is usually between 1.25 and 1.35. This means that for a certain inverter nominal export capacity the installed DC capacity will be higher by 25-35% in order to collect more energy during the days of low sun irradiation. As for the days with high irradiation, the inverter can curtail the excessive power and keep the active export within the limits. The DC/AC ratio should be calculated based on the total active power capacity of the inverters and not the total apparent power. For the module layout design, a high DC/AC ratio has been demonstrated, close to 1.43 (the total DC capacity is approximately 100 MWp so $100 \text{ MWp} / 70 \text{ MW} = 1.43$). This is quite high and it is possible that it will not be used during construction (less PV modules might actually be installed). However, this high ratio at preliminary design stage has the following advantages:

- In the future the price of solar PV systems is expected to fall significantly (an early 2018 IRENA report indicates that a further 40% drop in the LCOE of PV solar is expected by 2020). Depending on the year of construction for Timahoe North, the price of the solar system might be low enough, so a higher DC/AC ratio may be sensible. If however it does not make sense to use this high ratio, some of the tables can be removed from the design (preferably the tables that are further away from the inverters because these have the highest voltage drop due to the distance) and drop the ratio to the preferred levels.
- At preliminary design stage it is better to have a higher ratio in order to have some flexibility later to remove some tables if required. For example, during the final design, some land areas might be excluded from construction. In this case some tables will have to be removed and the DC/AC ratio will be reduced. Having a high initial DC/AC ratio will allow the final ratio to be kept at the required value.

8 Cabling

8.1 String DC cable

The cable that will be used for the strings is common solar cable 4 mm².

8.2 Main DC cable

The cable that will be used for the main DC cable (the cable that connects a CB with the inverter) has the following specifications:

Voltage capacity of main DC cable	1500 V
Conductors	Copper
Single or multicore	Multicore - double pole
Cross section	300 mm ²
Protection	Steel wire armour (SWA)
Insulation	Thermosetting 90 C
Installation method	Two methods: On a wire mesh tray run horizontally (every cable in a separate tray) and direct buried
Number of cables per trench	4
Depth	0.8 m
Width of trench (number of cables: 4)	0.75 m
Minimum distance between multicore cables	0.125 m

Table 8-3: DC Cable Specification

The main DC cables will be installed:

- On the back of the PV modules, on the PV tables, within wire mesh trays – one main DC cable per tray.
- Directly buried in the ground, as specified above. The main DC cable trench is shown in the drawing –“Trenches sections-1”.

For the specification of the main DC cable, the following regulations have been considered:

1. National Rules for Electrical Installations - 4th edition (Electrotechnical Council of Ireland): This regulation applies to the low voltage wiring systems in Ireland. The maximum voltage for which a DC system can be considered as low voltage is 1500 V so this regulation applies for the main DC cable because it is part of the 1500 V DC system of the solar farm.
2. Code of practice for grid connected solar photovoltaic systems (IET): As the solar sector in Ireland is premature at the moment, there is no local regulation for solar PV systems design. For this reason, this code of practice from the UK-based IET was used to facilitate the main DC cable selection.
3. Requirements for Electrical Installations (BS7671 - IET wiring regulations 17th edition): The IET code of practice for solar is referencing the BS7671 so the latter was also used for the specification of the main DC cable.

Other options for the main DC cable type and installation methods can be used but calculations are needed in order to ensure that the specifications are according to the above regulations. For example, if decentralised inverters were to be used for the final design, revised cable calculations will be needed.

9 Combiner boxes

Combiner boxes (CB) with 24 string DC inputs have been considered. It is possible to use CB with more string inputs e.g. 32 so the number of CB would be reduced. However if CBs with more string inputs are chosen longer main DC trenches would be required and fewer cables per trench would be allowed as the carrying current of each main DC cable would be higher.

If decentralised inverters are to be used, then DC Combiner Boxes probably will not be required as the strings are usually connected directly to the inverters.

10 Medium voltage cables and Switchboard

The configuration and design of the medium voltage cable is not part of the scope of this report. However a proposed MV cable layout and trench section has been prepared shown in drawing number "Trenches sections-2".

Also a containerised switchboard has been proposed to be installed in the northern site in order to connect all the inverters in this section of the site together.

In this way - instead of having every radial from the north side connected to the substation with a separate cable run - the switchboard will be connected with the main substation using only one cable run and this will reduce the length of cables and trenches required.

11 Substation

The design of the substation is not part of the scope of this report. The substation layout is shown on "Module layout" drawing.

12 Storage systems

The design includes approximately 15 MWh of battery storage in an area of the substation based on current battery technology. The final design output of the battery may increase subject to improvements in the energy density of batteries and agreement with the grid operator. The storage system consists of approximately eleven 40 ft containers which contain batteries. Each container is connected to two inverters and two transformers.

The substation design should be able to support the additional requirements of battery storage.

13 Earthing

An earth study will be required during the final design in order to determine the type, the size and the number of earthing elements that should be added to the PV system. Usually the following elements are added in a solar system:

- Direct buried non-insulated copper cable is installed around the perimeter of the PV tables and it is connected with the PV table frames. Earthing rods are used also.
- The fence and the gates are also earthed using earthing rods.

14 Access roads

The width of the access roads are 5.5 m in order to allow access for a range of vehicles like for example cranes / lorries / tractors.

The access roads positions are as per the “Module layout” drawing.

In some places the roads will cross over drains and typical detail of this type of road including culvert is shown in “Module layout” drawing.

15 Construction compound

Two construction compound areas are indicated in the “Module layout” drawing.

Once construction of the solar farm is complete, the temporary compound area in the northern section of the site will be available for solar development.

16 Peat storage areas

During the construction work, peat excavations will take place. A study was carried out to identify the volumes of peat to be excavated and stored. Seven peat storage areas are required on the site. The location of peat storage areas are shown on “Module layout” drawing and sections through the peat storage areas are shown on drawing with numbers QS-00218-01-D453-009 to QS-00218-01-D453-015.

17 Shadowing

Most of the trees within the project area should be removed to reduce shadowing effects.

Areas inside the solar development that the trees will remain are along the south bank of the drains in a buffer zone between 4-6m from the centre of the drain. Trees will remain to the west of the main access track in a zone approximately 30m in width.

18 Drainage

The drainage design is not in the scope of this report. A separate report and drawings are prepared on the project drainage design.

19 Fence and CCTV

The main perimeter fence of the solar farm will be deer fence at a height up to 2.2 m.

A sheep fence will also be installed around the drains inside the development area for H&S and silt control.

The actual CCTV system has not been determined yet. In the module layout CCTV cameras have been incorporated every 80 m all around the project main fence. Additional security systems like IR beam columns and on-fence detectors can be considered in the future.

Appendix 1 – PV Syst Report

PVSYST V6.61		26/07/18		Page 1/4					
Grid-Connected System: Simulation parameters									
Project :	BNM_TimahoeNorth_26072018								
Geographical Site	TimahoeNorth_Solargis	Country	Ireland						
Situation	Latitude	53.53° N	Longitude	-6.79° W					
Time defined as	Legal Time	Time zone UT	Altitude	82 m					
	Albedo	0.20							
Meteo data:	TimahoeNorth_Solargis	Solargis/FirstSolar - 2010							
Simulation variant : C- 9m-1t-34m-Tilt-20_SolarGIS_Y1_Losses_Final Report-26072018									
		Simulation date	26/07/18 10h39						
Simulation parameters									
Collector Plane Orientation	Tilt	20°	Azimuth	0°					
Models used	Transposition	Perez	Diffuse	Imported					
Horizon	Free Horizon								
Near Shadings	According to strings	Electrical effect	90 %						
PV Array Characteristics									
PV module	Si-poly	Model	Q.PLUS-G4.2 270						
Custom parameters definition	Manufacturer	Hanwha Q Cells							
Number of PV modules	In series	34 modules	In parallel	10934 strings					
Total number of PV modules	Nb. modules	371756	Unit Nom. Power	270 Wp					
Array global power	Nominal (STC)	100374 kWp	At operating cond.	90327 kWp (50°C)					
Array operating characteristics (50°C)	U mpp	948 V	l mpp	95264 A					
Total area	Module area	620833 m²	Cell area	542912 m²					
Inverter									
Custom parameters definition	Model	Sunny Central 2500-EV V5							
Characteristics	Manufacturer	SMA							
	Operating Voltage	778-1425 V	Unit Nom. Power	2500 kWac					
Inverter pack	Nb. of inverters	28 units	Total Power	70000 kWac					
PV Array loss factors									
Array Soiling Losses			Loss Fraction	0.5 %					
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s					
Wiring Ohmic Loss	Global array res.	0.31 mOhm	Loss Fraction	2.8 % at STC					
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC					
LID - Light Induced Degradation			Loss Fraction	1.0 %					
Module Quality Loss			Loss Fraction	-0.5 %					
Module Mismatch Losses			Loss Fraction	1.0 % at MPP					
Incidence effect (IAM): User defined IAM profile									
	0°	20°	30°	40°	50°	60°	70°	80°	90°
	1.000	1.000	1.000	1.000	1.000	1.000	0.950	0.750	0.000
System loss factors									
AC wire loss inverter to transfo	Inverter voltage	550 Vac tri							
	Wires: 3x30000.0 mm²	51 m	Loss Fraction	1.0 % at STC					
External transformer	Iron loss (Night disconnect)	98155 W	Loss Fraction	0.1 % at STC					
	Resistive/Inductive losses	0.0 mOhm	Loss Fraction	1.0 % at STC					
Unavailability of the system	3.6 days, 4 periods		Time fraction	1.0 %					
User's needs :	Unlimited load (grid)								

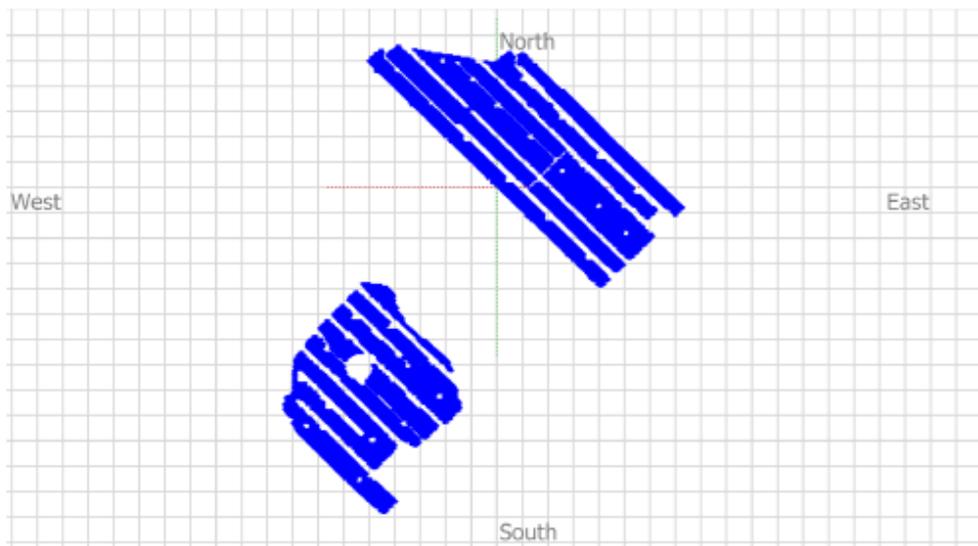
PV Syst Licensed to: ESB International (Ireland)

Grid-Connected System: Near shading definition

Project : BNM_TimahoeNorth_26072018
Simulation variant : C- 9m-1t-34m-Tilt-20_SolarGIS_Y1_Losses_Final Report-26072018

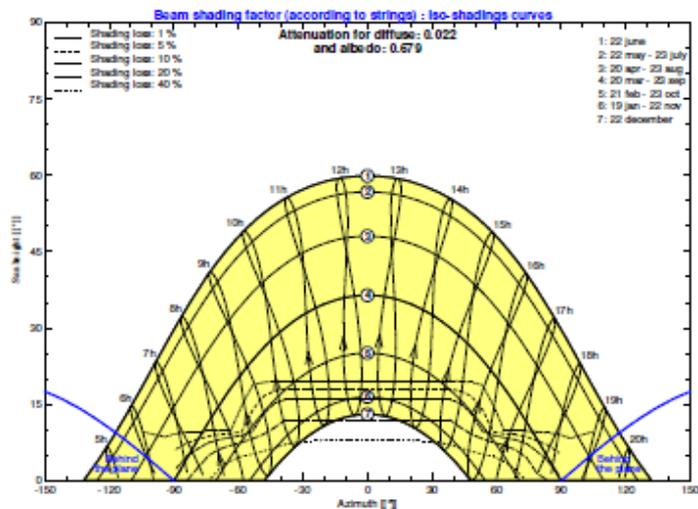
Main system parameters	System type	Grid-Connected	
Near Shadings	According to strings	Electrical effect	90 %
PV Field Orientation	tilt	azimuth	0°
PV modules	Model	Pnom	270 Wp
PV Array	Nb. of modules	Pnom total	100374 kWp
Inverter	Model	Pnom	2500 kW ac
Inverter pack	Nb. of units	Pnom total	70000 kW ac
User's needs	Unlimited load (grid)		

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

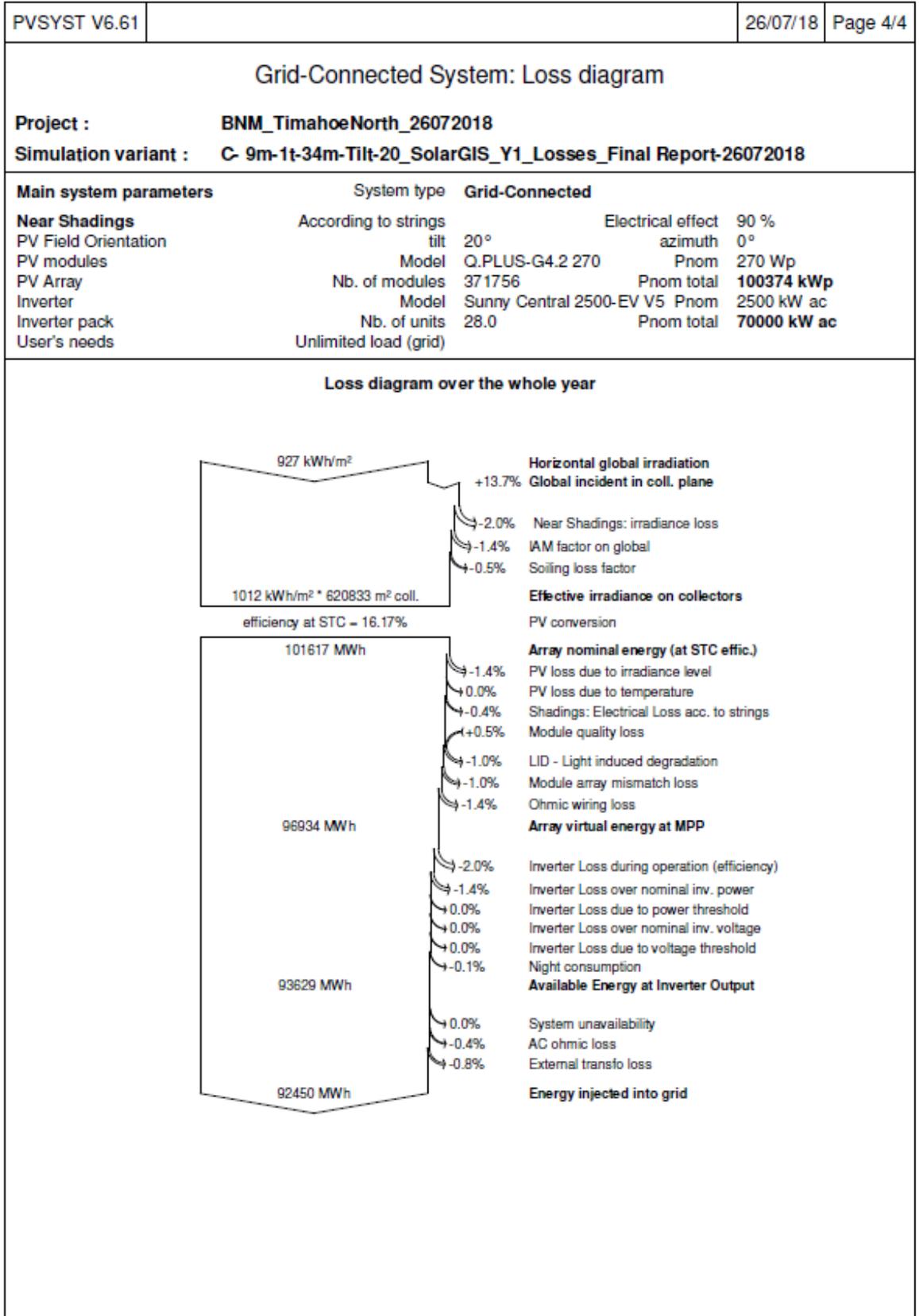
BNM_TimahoeNorth_26072018



PV Syst Licensed to: ESB International (Ireland)

PVSYST V6.61		26/07/18		Page 3/4																																																																																																																																								
Grid-Connected System: Main results																																																																																																																																												
Project :		BNM_TimahoeNorth_26072018																																																																																																																																										
Simulation variant :		C- 9m-1t-34m-Tilt-20_SolarGIS_Y1_Losses_Final Report-26072018																																																																																																																																										
Main system parameters		System type Grid-Connected																																																																																																																																										
Near Shadings		According to strings tilt		Electrical effect 90 %																																																																																																																																								
PV Field Orientation		20°		azimuth 0°																																																																																																																																								
PV modules		Model Q.PLUS-G4.2 270		Pnom 270 Wp																																																																																																																																								
PV Array		Nb. of modules 371756		Pnom total 100374 kWp																																																																																																																																								
Inverter		Model Sunny Central 2500-EV V5		Pnom 2500 kW ac																																																																																																																																								
Inverter pack		Nb. of units 28.0		Pnom total 70000 kW ac																																																																																																																																								
User's needs		Unlimited load (grid)																																																																																																																																										
Main simulation results		Produced Energy 92450 MWh/year																																																																																																																																										
System Production		Performance Ratio PR 87.38 %		Specific prod. 921 kWh/kWp/year																																																																																																																																								
<p>Normalized productions (per installed kWp): Nominal power 100374 kWp</p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="359 806 877 1176"> <p>Normalized productions (per installed kWp): Nominal power 100374 kWp</p> <p>Legend: Lc: Collection Loss (PV array losses) 0.28 kWh/kWp/day Li: System Loss (inverter, ...) 0.09 kWh/kWp/day Yl: Produced useful energy (inverter output) 2.52 kWh/kWp/day</p> </div> <div data-bbox="925 806 1452 1176"> <p>Performance Ratio PR</p> <p>PR: Performance Ratio (Yl / Yc) 0.874</p> </div> </div> <p style="text-align: center;">C- 9m-1t-34m-Tilt-20_SolarGIS_Y1_Losses_Final Report-26072018</p> <p style="text-align: center;">Balances and main results</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th></th> <th>GlobHor</th> <th>DiffHor</th> <th>T Amb</th> <th>GlobInc</th> <th>GlobEff</th> <th>EArray</th> <th>E_Grid</th> <th>PR</th> </tr> <tr> <th></th> <th>kWh/m²</th> <th>kWh/m²</th> <th>°C</th> <th>kWh/m²</th> <th>kWh/m²</th> <th>MWh</th> <th>MWh</th> <th></th> </tr> </thead> <tbody> <tr><td>Jan. 10</td><td>19.7</td><td>13.06</td><td>5.59</td><td>31.8</td><td>29.4</td><td>2786</td><td>2688</td><td>0.835</td></tr> <tr><td>Feb. 10</td><td>35.9</td><td>22.10</td><td>5.32</td><td>49.7</td><td>48.0</td><td>4749</td><td>4591</td><td>0.920</td></tr> <tr><td>Mar. 10</td><td>70.3</td><td>41.86</td><td>6.54</td><td>86.7</td><td>83.8</td><td>8243</td><td>7975</td><td>0.916</td></tr> <tr><td>Apr. 10</td><td>109.4</td><td>62.86</td><td>7.71</td><td>122.0</td><td>117.7</td><td>11243</td><td>10877</td><td>0.888</td></tr> <tr><td>May 10</td><td>139.4</td><td>78.79</td><td>10.45</td><td>145.8</td><td>140.5</td><td>13035</td><td>12803</td><td>0.862</td></tr> <tr><td>June 10</td><td>140.8</td><td>81.47</td><td>12.64</td><td>142.2</td><td>136.9</td><td>12806</td><td>12192</td><td>0.854</td></tr> <tr><td>July 10</td><td>130.1</td><td>80.90</td><td>14.83</td><td>132.4</td><td>127.4</td><td>11877</td><td>11493</td><td>0.865</td></tr> <tr><td>Aug. 10</td><td>115.3</td><td>67.83</td><td>14.71</td><td>125.4</td><td>120.8</td><td>11241</td><td>10871</td><td>0.864</td></tr> <tr><td>Sep. 10</td><td>78.4</td><td>48.57</td><td>12.67</td><td>88.8</td><td>85.8</td><td>8159</td><td>7898</td><td>0.886</td></tr> <tr><td>Oct. 10</td><td>50.5</td><td>30.46</td><td>10.33</td><td>67.6</td><td>65.4</td><td>6338</td><td>6133</td><td>0.904</td></tr> <tr><td>Nov. 10</td><td>23.8</td><td>16.49</td><td>7.47</td><td>35.5</td><td>33.8</td><td>3228</td><td>3116</td><td>0.875</td></tr> <tr><td>Dec. 10</td><td>15.3</td><td>10.21</td><td>5.70</td><td>26.4</td><td>23.3</td><td>2116</td><td>2032</td><td>0.768</td></tr> <tr><td>Year</td><td>926.8</td><td>553.98</td><td>9.51</td><td>1054.1</td><td>1012.2</td><td>95800</td><td>92450</td><td>0.874</td></tr> </tbody> </table> <p>Legends: GlobHor Horizontal global irradiation GlobEff Effective Global, corr. for IAM and shadings DiffHor Horizontal diffuse irradiation EArray Effective energy at the output of the array T Amb Ambient Temperature E_Grid Energy injected into grid GlobInc Global incident in coll. plane PR Performance Ratio</p>							GlobHor	DiffHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	PR		kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh		Jan. 10	19.7	13.06	5.59	31.8	29.4	2786	2688	0.835	Feb. 10	35.9	22.10	5.32	49.7	48.0	4749	4591	0.920	Mar. 10	70.3	41.86	6.54	86.7	83.8	8243	7975	0.916	Apr. 10	109.4	62.86	7.71	122.0	117.7	11243	10877	0.888	May 10	139.4	78.79	10.45	145.8	140.5	13035	12803	0.862	June 10	140.8	81.47	12.64	142.2	136.9	12806	12192	0.854	July 10	130.1	80.90	14.83	132.4	127.4	11877	11493	0.865	Aug. 10	115.3	67.83	14.71	125.4	120.8	11241	10871	0.864	Sep. 10	78.4	48.57	12.67	88.8	85.8	8159	7898	0.886	Oct. 10	50.5	30.46	10.33	67.6	65.4	6338	6133	0.904	Nov. 10	23.8	16.49	7.47	35.5	33.8	3228	3116	0.875	Dec. 10	15.3	10.21	5.70	26.4	23.3	2116	2032	0.768	Year	926.8	553.98	9.51	1054.1	1012.2	95800	92450	0.874
	GlobHor	DiffHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	PR																																																																																																																																				
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh																																																																																																																																					
Jan. 10	19.7	13.06	5.59	31.8	29.4	2786	2688	0.835																																																																																																																																				
Feb. 10	35.9	22.10	5.32	49.7	48.0	4749	4591	0.920																																																																																																																																				
Mar. 10	70.3	41.86	6.54	86.7	83.8	8243	7975	0.916																																																																																																																																				
Apr. 10	109.4	62.86	7.71	122.0	117.7	11243	10877	0.888																																																																																																																																				
May 10	139.4	78.79	10.45	145.8	140.5	13035	12803	0.862																																																																																																																																				
June 10	140.8	81.47	12.64	142.2	136.9	12806	12192	0.854																																																																																																																																				
July 10	130.1	80.90	14.83	132.4	127.4	11877	11493	0.865																																																																																																																																				
Aug. 10	115.3	67.83	14.71	125.4	120.8	11241	10871	0.864																																																																																																																																				
Sep. 10	78.4	48.57	12.67	88.8	85.8	8159	7898	0.886																																																																																																																																				
Oct. 10	50.5	30.46	10.33	67.6	65.4	6338	6133	0.904																																																																																																																																				
Nov. 10	23.8	16.49	7.47	35.5	33.8	3228	3116	0.875																																																																																																																																				
Dec. 10	15.3	10.21	5.70	26.4	23.3	2116	2032	0.768																																																																																																																																				
Year	926.8	553.98	9.51	1054.1	1012.2	95800	92450	0.874																																																																																																																																				

PVsySt Licensed to: ESB International (Ireland)



PV Syst Licensed to ESB International (Ireland)